

# Potato Chip Quality and Frying Oil Stability of High Oleic Acid Soybean Oil

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**ABSTRACT:** High oleic soybean (HOSBO) and low linolenic acid soybean (LLSBO) oils were evaluated individually and in a 1:1 blend along with cottonseed oil (CSO) to determine frying oil stabilities and the flavor quality and stability of potato chips. Potato chips were fried in the oils for a total of 25 h. Potato chips and oils were sampled periodically for sensory data, gas chromatographic volatile compounds, free fatty acids, and total polar compounds. Total polar compounds levels decreased with increasing amounts of oleic acid. The LLSBO had the highest overall increase (17.3%) in total polar compounds from 0 to 25 h of frying. Flavor evaluations of fresh and aged (0, 1, 3, 5, and 7 wk at 25 °C) potato chips showed differences between potato chips fried in different oil types. Potato chips fried in either LLSBO or in the 1:1 blend had significantly higher intensities of deep fried flavor than the chips fried in HOSBO. Potato chips fried in HOSBO, which had 2% linolenic acid and 1.3% linoleic acid, had significantly higher fishy flavor intensity than chips fried in the other oils. The presence of linoleic acid at a level lower than the amount of linolenic acid probably allowed for the fishy flavors from the degradation of linolenic acid in HOSBO to become more apparent than if the linoleic acid level was higher than linolenic acid. Hexanal was significantly higher in potato chips fried in LLSBO than in the chips fried in the other oils, indicating low oxidative stability during storage. Blending HOSBO with LLSBO in a 1:1 ratio not only improved flavor quality of chips compared with those fried in HOSBO, but also improved oil fry life and oxidative stability of chips compared with LLSBO.

**Keywords:** flavor, frying, hexanal, linolenic acid, potato chips, soybean oil

## Introduction

Altering fatty acid compositions of oilseeds by plant breeding is now commonly used to improve the oxidative stability of oils. For example, linolenic acid content in canola and soybean oils is usually decreased to less than 3% (Miller and White 1988; Warner and Mounts 1993; Mounts and others 1998) and oleic content of safflower, canola, and sunflower has been increased above 80% (Fuller and others 1967; Niemela and others 1996; Petukhov and others 1999). Decreasing the linolenic acid and increasing the oleic acid of canola oil produced good frying stability as measured by total polar compounds; however, potato chips fried in canola oil containing 78% oleic acid, 19% linoleic acid, and 4% linolenic acid had less fried potato flavor intensity than potato chips fried in canola oil with 64% oleic acid, 24% linoleic acid, and 3% linolenic acid, presumably because of the lower linoleate content (Warner and others 1994). In determining ideal fatty acid levels, it should be kept in mind that oleic acid levels should not be too low nor linoleic acid too high because the frying oil and fried food can have lower stability. For example, potato chips fried in oils with a range of linoleic acid from 17% to 78% showed a high correlation coefficient of 0.87 ( $P < 0.05$ ) between increasing linoleic acid and decreasing oxidative stability (Warner and others 1974). Evans and others (1965) found that the linolenic acid content needed to be decreased to less than 5% to improve the flavor quality and oxidative stability of soybean oil when they were evaluated as salad oils after storage. The target for linolenic acid needs to be even lower than 5% for frying oils because linolenic acid—containing vegetable oils such as canola and soybean are well known to produce off-flavors and odors such as fishy when they were

exposed to high-temperature heating (Evans and others 1965; Eskin and others 1989). Based on these studies, increasing the content of oleic acid of oilseeds and decreasing the linoleic and linolenic acids increases oxidative stability of oils. Research has been previously reported on safflower, sunflower, corn, and canola oils with oleic acid levels increased to 55% to 90% (Fuller and others 1966; Fuller and others 1967; Purdy and Campbell 1967; Fuller and others 1971; Eskin and others 1989; Warner and Knowlton 1997) to create a range of mid-oleic to high-oleic oils that have increased stability. Now, soybeans have been modified transgenically to have high levels of oleic acid to improve oil stability. This new cultivar of soybeans that has 85% oleic acid, 2% linolenic acid, and 1.3% linoleic was of interest because of the high level of oleic acid and the unusual ratio of linoleic to linolenic acid. The objective of this study was to determine the effects of modifying the fatty acid composition of soybean oil—increasing oleic acid content to very high levels (85%) and decreasing linoleic and linolenic acid contents to less than 2%—on the frying stability of high oleic soybean oil (HOSBO). HOSBO was compared in frying studies with low linolenic acid soybean (LLSBO), a 1:1 HOSBO:LLSBO blend, and cottonseed oil; the storage stability and flavor characteristics of potato chips were also determined.

## Materials and Methods

### Materials

Cottonseed oil (CSO) (Archer, Daniels, Midland Co., Decatur, Ill., U.S.A.), low linolenic acid soybean oil (LLSBO) (Protein Technologies Intl., St. Louis, Mo., U.S.A.), and high oleic acid soybean oil (HOSBO) (Protein Technologies Intl.) were commercially processed. A 1:1 blend of HOSBO and LLSBO was prepared. Oils contained no additives other than citric acid. Nr 1 Idaho Russet potatoes were obtained from a local market to prepare potato chips.

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## Instrumental and chemical analyses of oils

Fatty acid compositions of the initial oils were determined in duplicate by capillary gas chromatographic (GC) analysis with a Hewlett-Packard 5890 GC (Wilmington, Del., U.S.A.) equipped with a SP2330 column (30 m, 0.20-mm inner dia, 0.20- $\mu$ m film thickness) (Supelco, Bellefonte, Pa., U.S.A.). Column temperature was 1st held at 190 °C for 5 min and then was programmed to 230 °C at 20 °C/min. The injector was held at 250 °C and the detector at 260 °C. Free fatty acid (FFA) content was measured as % oleic acid by AOCS method Ca 5a-40 (AOCS 1998). Initial oxidation of the fresh oils was measured in duplicate by peroxide value (AOCS method Cd 8-53) (AOCS 1998). The oxidative stability index of the fresh oils was measured at 110 °C according to the AOCS method Cd 12b-92 (AOCS1998). Total polar compound levels of the fresh and used frying oils were determined in duplicate by the AOCS column chromatography method Cd 20-91 (AOCS 1998). Hexanal content of the aged potato chips was analyzed in triplicate with a purge and trap apparatus equipped with a test tube adapter (Tekmar model 3000, Tekmar-Dohrmann Co., Cincinnati, Ohio, U.S.A.) coupled with a Varian model 3400 gas chromatograph (GC) and a Saturn model 3 ion trap mass spectrometer (MS) (Varian, Inc., Walnut Creek, Calif., U.S.A.). A 50-mg potato chip sample was placed in a 1.9  $\times$  7.6 cm test tube and heated at 100 °C for 9 min preheat time. Volatile compounds were trapped on a 30.5 cm Tenax nr 1 trap, with 10 min sample purge time, 170 °C for 6 min desorbing, 180 °C MCS desorb temperature, 160 °C GC transfer line and valve temperature. Volatile compounds were introduced onto a DB-1701 GC capillary column (30 m  $\times$  0.32 mm with 1- $\mu$ m film thickness) (J & W Scientific, Folsom, Calif., U.S.A.). The column was held at -20 °C for 2 min and then heated from -20 °C to 233 °C at 3 °C /min. Column helium flow rate was 2 mL/min with 28-mL/min injector split vent flow. The GC injector was set at 240 °C, and the line to the MS was set at 230 °C. The ion trap MS operated in EI mode with a mass scan range of 23 to 400 m/z over 0.8 s. The filament emission current was 25 micro amps, the axial modulation was 2.1 volts, the manifold heater was set at 160 °C, and the filament/multiplier delay was 2.5 min. Compound structural identifications were made both from spectral comparisons with the NIST 92 mass spectrometry library (Varian, Inc.) and from retention time comparisons with standard compounds.

## Frying stability test

The frying protocol included intermittent frying at 190 °C with total heating/frying time of 25 h over 3 d. Initially, 9 L of each oil was placed in 16 L capacity fryers (Cecilware, Model EL250, West Palm Beach, Fla. U.S.A.). Fresh Idaho Russet potatoes were peeled and then sliced 1 mm thick and rinsed several times in cold water. Slices were dried and then fried in 120-g batches. Oil samples were taken at the end of 1, 5, 15, and 25 h of frying. Fresh oil was added as makeup oil after 5, 10, 15, and 20 h of frying to maintain the original amount of oil in the fryer. Samples of potato chips were collected for analyses after 1, 5, 15, and 25 h of frying but before makeup oil was added. Potato chips were placed in 1 L wide-mouth glass jars with air in the headspace, and the jar was closed with a screw cap. Potato chips were either aged in the jars in the dark for 1, 3, 5, and 7 wk at 25 °C and then frozen until analysis or frozen immediately as 0-time samples. The frying protocol was repeated twice with different lots of the oils.

## Sensory analysis

A 16-member analytical descriptive sensory panel, trained and experienced in evaluating fried foods, were presented with 5-g crushed potato chip samples at room temperature in 59.2 mL (2 oz) plastic souffle cups with snap-on lids (Solo Cup Co., Urbana, Ill., U.S.A.). Each panelist received 4 coded, randomized samples of each fry time at each storage time per session. Panelists rated the potato chips for intensities

**Table 1 — Fatty acid compositions (%) of cottonseed oil (CSO), high oleic acid soybean oil (HOSBO), low linolenic acid soybean oil (LLSBO), and 1:1 blend of HOSBO:LLSBO**

Fatty acids	CSO	HOSBO	HOSBO:LLSBO	LLSBO
C14:0	0.9	0.0	0.0	0.0
C16:0	25.5	7.3	9.2	10.8
C16:1	0.6	0.0	0.0	0.0
C18:0	2.5	3.4	4.0	4.5
C18:1	17.7	85.1	55.5	26.1
C18:2	52.2	1.3	28.9	55.4
C18:3	0.1	2.0	2.0	2.0
C20:0	0.3	0.4	0.4	0.4
C22:0	0.2	0.4	0.4	0.4

of individual flavors including deep fried, potato, stale, rancid, cardboard, and fishy on a 10-point intensity scale with 0 = no intensity and 10 = strong flavor intensity. They also rated overall flavor quality of the potato chips on a 10-point quality scale with 10 = excellent and 1 = bad. All sensory evaluations were conducted in our research center in a panel room with individual booths, temperature controlled and with red lighting to mask color differences between samples (Warner 1995). Data from the 2 frying series were pooled and statistically analyzed.

## Statistical analysis

Data were evaluated by analysis of variance (Snedecor 1956). Statistical significance is expressed at the  $P \leq 0.05$  level unless otherwise indicated.

## Results and Discussion

### Fatty acid composition

Compositions of the oils showed that the linolenic acid contents were 2% for both HOSBO and LLSBO (Table 1). Compared with unmodified soybean oil that has a typical linoleic acid content of approximately 53%, the linoleic acid content of LLSBO was increased slightly because of decreased linolenic acid levels. Linoleic acid contents were much less for HOSBO at 1.3% than for LLSBO at 55.4%. The 1:1 blend of HOSBO:LLSBO had 28.9% linoleic acid. Oleic acid levels were 85.1% in the HOSBO, 26% in the LLSBO, and 55.5% in the blend. Composition of the CSO was typical for this oil type (Warner and others 1997). Saturated fat levels were similar in both soybean oils.

### Initial oil quality

Initially, peroxide values were 0.5 for CSO, 0.8 for LLSBO, and 0.0 for HOSBO. In the fresh oils, total polar compound levels (Table 2) were low in the LLSBO at 1.2% and in the HOSBO at 1.7%, but the CSO had 6.1% total polar compounds, which is typical for a fresh unheated CSO (Warner and others 1997). In the fresh oils, free fatty acid levels were 0.07% for LLSBO, 0.08% for HOSBO, and 0.09% for CSO. The oxidative stability index for each oil was 57.5 h for HOSBO; 19.4 h for the 1:1 blend of HOSBO:LLSBO; 11.5 h for CSO; and 8.7 h for LLSBO, indicating that under these oxidation conditions, HOSBO had significantly better oxidative stability than the other oils. The LLSBO was the least stable followed closely by the CSO. Even though the blend was equal parts of HOSBO and LLSBO, the OSI value was closer to the value of the LLSBO than a mean of the OSI values of the 2 oils tested separately.

### Frying stability

The percent of total polar compound is a chemical measure of degradation products formed in frying oils. After 5 h of frying, HOSBO had 5.6% total polar compounds, the 1:1 blend had 6.9% and the LLSBO had 8.5% indicating a significant positive effect from increased oleic acid content (Table 2). By 25 h of frying, the HOSBO still had a signif-

**Table 2—Total polar compounds and free fatty acids for cottonseed oil (CSO), high oleic soybean oil (HOSBO), low linolenic acid soybean oil (LLSBO), and 1:1 HOSBO: LLSBO oils used for frying potato chips for 0, 1, 5, 15, and 25 h**

Hours of frying at 190 °C	CSO	HOSBO	HOSBO:LLSBO	LLSBO
Total polar compounds (%) <sup>a</sup>				
0	6.1a	1.7b	1.4b	1.2b
1	7.2a	2.1b	1.9b	1.7b
5	11.6a	5.6b	6.9c	8.5d
15	16.3a	9.6b	11.2c	15.1d
25	18.1a	12.5b	14.4c	18.5a
Free fatty acids (% oleic) <sup>a</sup>				
0	0.09a	0.08a	0.08a	0.07a
1	0.10a	0.09a	0.08a	0.08a
5	0.13a	0.15a	0.09b	0.09b
15	0.16a	0.18a	0.13b	0.12b
25	0.19a	0.21a	0.16b	0.15b

<sup>a</sup>Values with letters in common in each row are not significantly different ( $P \leq 0.05$ ).

ificantly lower percentage of polar compounds than any of the other oils. CSO and LLSBO had the highest amounts of polar compounds at 25 h. These results agree with those of Petukhov and others (1999) who found that high oleic canola oil had significantly lower polar compounds than low linolenic acid canola after frying. Free fatty acid analysis was used to determine effects of hydrolysis in the frying oils. FFA increased with increasing frying time in all oils (Table 2). At frying times of 5, 15, and 25 h, HOSBO had significantly higher FFA levels than did CSO, LLSBO, or the blend.

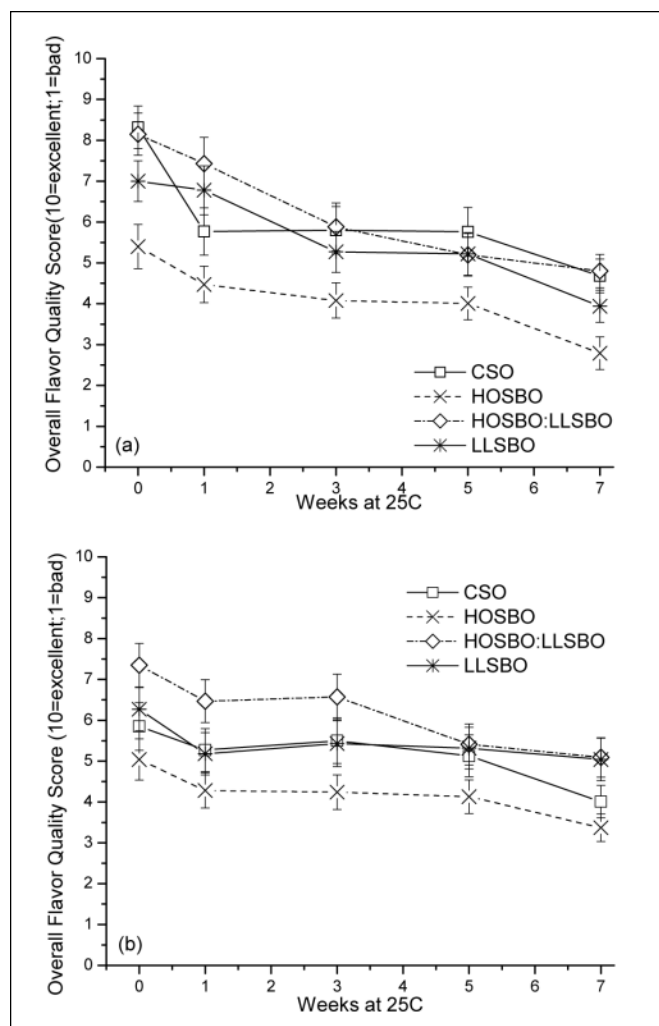
### Flavor quality of potato chips

CSO was included in the study because it has been an industry standard in the United States for producing food with desirable flavor quality. Overall flavor quality scores of all potato chip samples decreased with increasing frying times and with increasing storage at room temperature; however, the effect of storage was greater than the effect of frying time. After 5 h of oil use, the potato chips fried in HOSBO had significantly lower flavor quality scores at all storage times than the chips fried in LLSBO, the blend, or CSO (Figure 1). The potato chips fried in either CSO or the blend had the highest flavor quality scores at 0 time, but no significant differences were noted between these 2 samples and LLSBO at 1, 3, and 5 wk of storage. After 7 wk of storage, the potato chips fried in the blend had significantly higher flavor quality than the chips fried in HOSBO or LLSBO. The potato chips sampled at 25 h of frying showed similar patterns of flavor quality as chips fried in 5 h oil, but with fewer significant differences between oil types (Figure 1). For example, no significant differences were noted at 0 and 7 wk between the potato chips fried in CSO or HOSBO. After 5 and 7 wk of storage, no significant differences were found between potato chips fried in LLSBO or the blend. The overall flavor quality scores for the potato chips sampled at 5 h were similar to those obtained at the 1 h frying time, and those at 25 h were similar to the 15 h frying time; therefore, flavor quality scores for the 1 h and 15 h times are not shown. The potato chips fried in the oils used for 5 h are typical of potato chips fried in commercial operations because the chemical indices of FFA and total polar compounds for the oils in this study were similar to what might be found commercially (Gupta, 2002, private communication).

The types and intensities of positive and negative flavors in the potato chips can help explain the differences in overall flavor quality scores. For example, the deep fried flavor intensity of the potato chips fried in the 5-h HOSBO was significantly lower than the potato chips fried in CSO, LLSBO, or the blend at 0 time and after 1 wk of storage (Figure 2). At 3 and 5 wk of storage, no significant differences were

found among the 4 oil samples. However, by the 7th wk of storage, the potato chips fried in CSO or the blend had the highest deep fried flavor intensity. This may partially explain the higher overall flavor quality score for the sample fried in the blend (Figure 1), although lower intensities of negative flavors also affect the overall flavor quality as can be seen in Figure 3 through 5. Deep fried flavor intensities of potato chips fried in oils used for 1, 15, or 25 h were similar to those of the 5 h oils and are therefore not presented. Few differences were found in the intensities of potato flavor in the potato chips fried in the oils. Initial intensity levels were in the 3 to 4 range in the fresh potato chips and decreased slightly with increasing frying time and increasing storage of all the chips (data not shown).

Stale flavor is usually evident in the early stages of oxidation as the intensity of positive flavors such as deep fried are decreasing but before flavors indicative of greater oxidation such as rancid are present at higher levels. In this study, stale flavor increased with increasing storage time for all potato chip samples (Figure 3). Potato chips fried in HOSBO and LLSBO used for 5 h of frying had significantly higher intensities of stale flavor than the potato chips fried in either CSO or the blend at the both the 5 and 7 wk storage times. The lower intensities of deep fried flavor in the HOSBO samples may have resulted in the increased perception



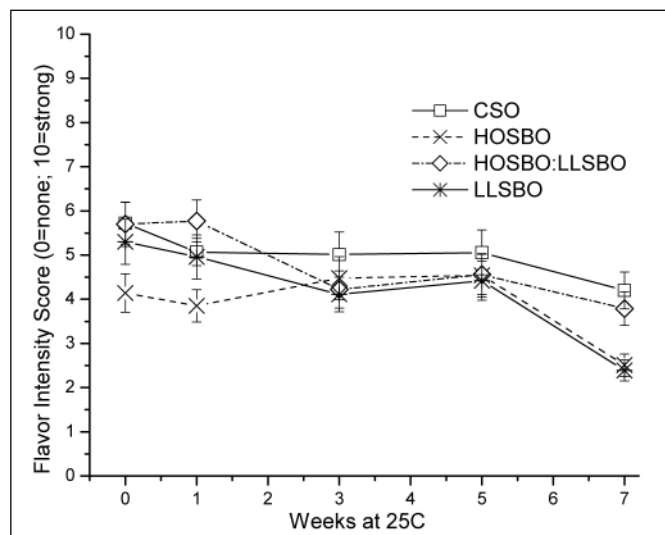
**Figure 1—Flavor quality scores for potato chips fried in cottonseed oil (CSO); high oleic soybean oil (HOSBO); 1:1 blend of HOSBO and low linolenic acid soybean oil (LLSBO); or LLSBO used for 5 h (a) or 25 h (b) of frying at 190 °C and aged at 0, 1, 3, 5, or 7 wk at 25 °C**

of stale flavor in this sample, whereas the potato chips fried in the CSO or the blend have more deep fried flavor to possibly help mask stale flavor that develops as linoleic acid oxidizes. Potato chips fried in HOSBO used for 25 h and aged for 1, 3, or 5 wk had more stale flavor intensity than the other potato chip samples. The chips fried in the blend had less stale flavor than the other samples at all storage times, indicating less oxidation and/or a possible masking of stale flavor from the higher intensity of deep fried flavor. This is another possible reason why the potato chips fried in the HOSBO:LLSBO blend had significantly high overall flavor quality scores than chips fried in HOSBO (Figure 1). Data for cardboard flavor are not presented because they were similar to the results for the stale flavor.

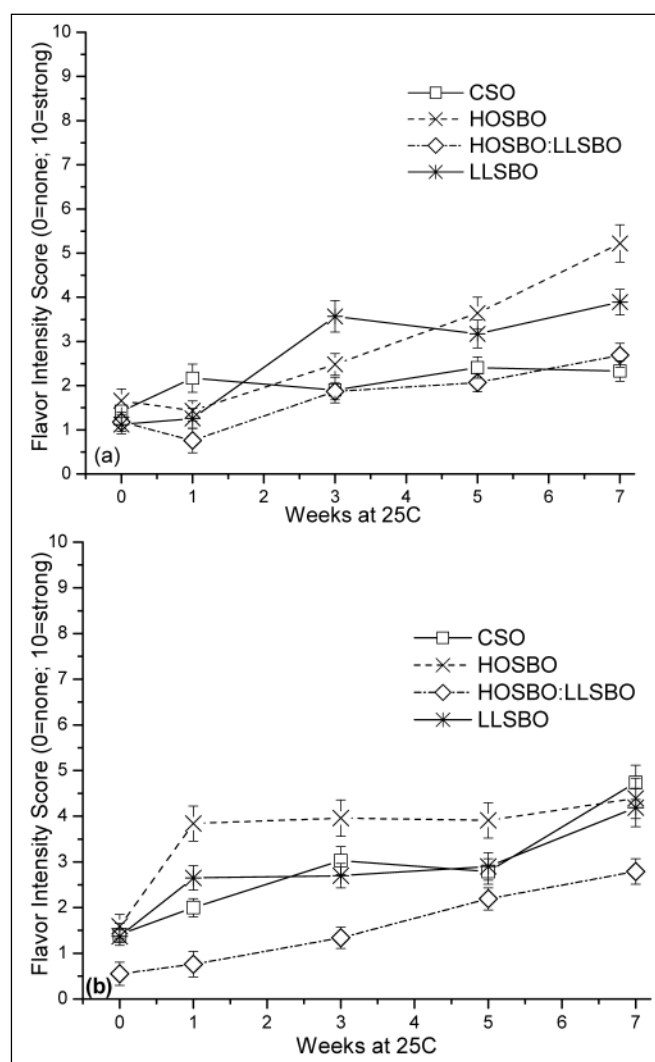
Intensity levels of rancid flavor in the aged potato chips were at very low levels (<2.1 on the 0 to 10 intensity scale) in all samples. Although rancid flavor is usually produced from degradation products of linoleic acid, the potato chips fried in HOSBO inexplicably had higher intensity levels of rancid flavor than the potato chips fried in any of the other oils, which all had higher amounts of linoleic acid. Rancid flavor is characteristic of oxidized linoleate-containing oils (Frankel 1985); however, we observed unusual results in these frying oils in which the potato chips fried in HOSBO had higher levels of rancid flavor intensity than potato chips fried in the other oils. Potato chips fried in all 3 of the other oil types, in which all had higher amounts of linoleic acid than the HOSBO, had significantly lower rancid intensities than the potato chips fried in HOSBO (Figure 4). This atypical result was noted in both frying trials using different batches of oil and is unexpected because of the low 1.3% linoleic acid content of the HOSBO. We would expect that the chips fried in the higher linoleate oils, LLSBO, CSO, and the blend would have more rancid flavor than that produced by the HOSBO. Data for hexanal contents of the potato chips presented in the next section shows low levels of hexanal in the chips fried in HOSBO. Hexanal is usually considered a good marker for rancid flavor. We cannot explain these unusual results. We believe that the results are genuine because the descriptive sensory panel was well trained and experienced in evaluating lipid-containing foods with rancid flavor. In addition, the same results were observed in 2 trials with different batches of the same oil types. The limited amount of storage time (7 wk) for these potato chips may be a factor in the low levels of rancid flavor in the linoleate-containing CSO and LLSBO. The higher rancid flavor intensity in the chips

fried in HOSBO was found at all sampling times, but only results from the 5-h and 25-h sampling times are included (Figure 4).

Fishy flavor is usually characteristic of oils containing linolenic acid. Soybean and canola oils with 7% to 10% linolenic acid typically have a characteristic fishy odor and flavor when they are heated to frying temperature, and foods fried in these oils can have this same odor and flavor. In previous studies of fried foods, we found that a fishy flavor was most noticeable in the foods fried in fresher rather than abused oils and in fresh and in slightly aged foods rather than those foods aged for longer periods (Warne K 1998, unpublished data). Although stale and rancid flavors are usually produced by increased fry time of the oil and/or by increased storage time of the fried food, fishy flavor is at higher intensity levels during the early stages of frying, possibly because the volatile compounds producing this flavor degrade and/or the fishy flavor is partly masked by other off-flavors that develop during later periods of frying. In most of the comparisons in this study, we found that the potato chips fried in HOSBO had higher levels of fishy flavor than any of the potato chips samples fried in the other oils (Figure 5). In 17 of 20 comparisons at the various frying time/storage times, the differences in fishy flavor intensity between the chips fried in HOSBO



**Figure 2—Deep fried flavor intensity of potato chips fried in cottonseed oil (CSO); high oleic soybean oil (HOSBO); 1:1 blend of HOSBO and low linolenic acid soybean oil (LLSBO); or LLSBO used for 5 h of frying at 190 °C and aged at 0, 1, 3, 5, or 7 wk at 25 °C**



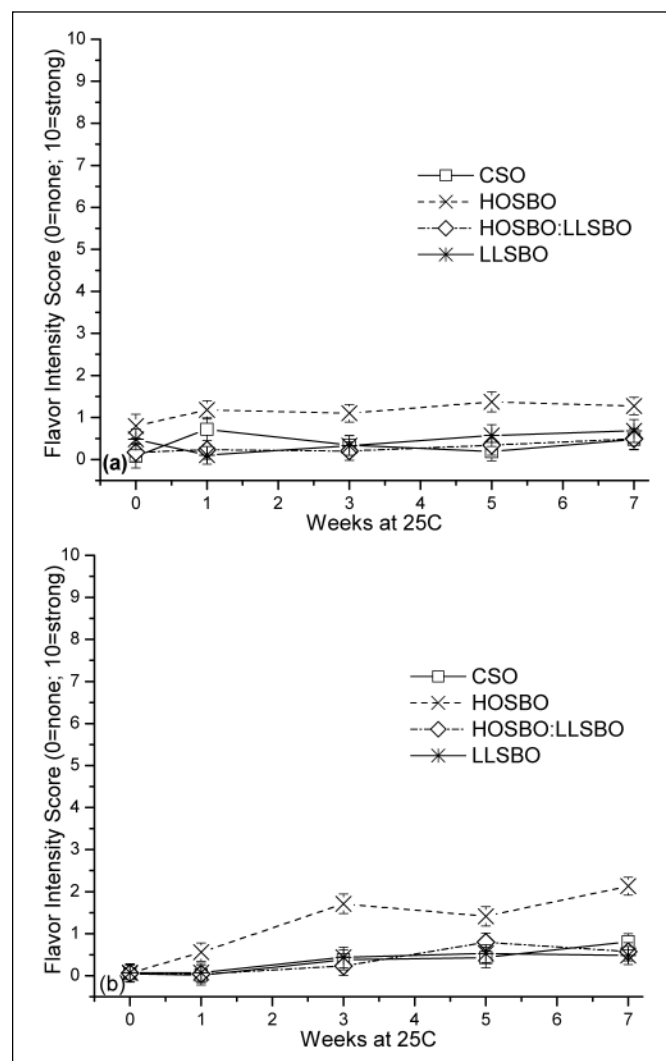
**Figure 3—Stale flavor intensity of potato chips fried in cottonseed oil (CSO); high oleic soybean oil (HOSBO); 1:1 blend of HOSBO and low linolenic acid soybean oil (LLSBO); or LLSBO used for 5 h (a) or 25 h (b) of frying at 190 °C and aged at 0, 1, 3, 5, or 7 wk at 25 °C**

BO and the other oils were significant. This effect is probably because of the highly unusual relationship of the levels of linoleic and linolenic acid in the HOSBO. HOSBO contains more linolenic acid (2%) than linoleic acid (1.3%). Volatile degradation products from linoleic acid produce both positive and negative flavors that could help mask the fishy flavor from linolenic acid; however, when the linoleic acid level is lower than the linolenic acid, this effect is probably minimal. As expected, the potato chips sampled at 15 h (data not shown) and 25 h had less fishy flavor intensity than those sampled at 1 and 5 h (Figure 5). In addition, the fishy flavor intensity in the chips fried in the HOSBO generally decreased with increasing week of storage at 25 °C.

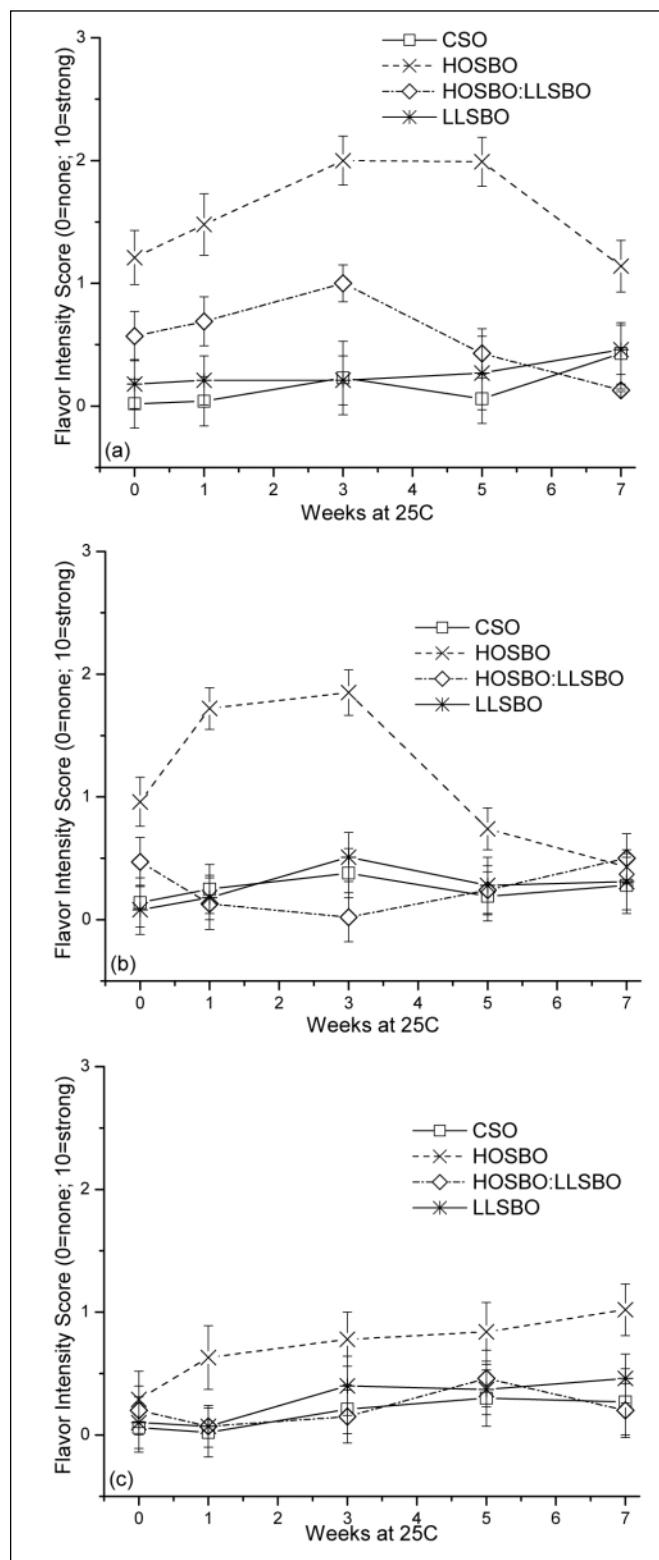
### Oxidative stability of potato chips

Hexanal was monitored as a marker for oxidation levels in the potato chips (Frankel 1985). Volatile compounds typical of linolenic acid oxidation were present at very low levels and showed very few differences at the levels of storage used in this study. In addition, 1 compound that is known to have a fishy odor, 2,4,7-decatrinal, was not detectable. Volatile compound analysis was conducted on potato chips sampled at 5, 15, and 25 h of oil use and then aged at 1, 3, 5, and 7 wk at 25 °C. At the

5-h sampling time, few significant differences in hexanal amounts were found between oil types until later storage times (Figure 6). By 7 wk of storage, the chips fried in HOSBO used for 5 h had the least amount of hexanal followed by the chips fried the blend, then CSO. The chips fried



**Figure 4—Rancid flavor intensity of potato chips fried in cottonseed oil (CSO); high oleic soybean oil (HOSBO); 1:1 blend of HOSBO and low linolenic acid soybean oil (LLSBO); or LLSBO used for 5 h (a) or 25 h (b) of frying at 190 °C and aged at 0, 1, 3, 5, or 7 wk at 25 °C**



**Figure 5—Fishy flavor intensity of potato chips fried in cottonseed oil (CSO); high oleic soybean oil (HOSBO); 1:1 blend of HOSBO and low linolenic acid soybean oil (LLSBO); or LLSBO used for 1 h (a), 5 h (b), or 25 h (c) of frying at 190 °C and aged at 0, 1, 3, 5, or 7 wk at 25 °C**

in LLSBO had the highest amount of hexanal. The same relationship was noted in the chips fried in oils used for 15 h (data not shown) and 25 h (Figure 6), but the ppm levels were higher. Lahtinen and others (1996) also found that aged potato chips fried in high oleic oil (sunflower) had less hexanal development than chips fried in oil with low levels of oleic acid. The potato chips fried in HOSBO were the most oxidatively stable as judged by hexanal content, which is an expected result. Although rancid flavor and hexanal content usually are highly correlated, the potato chips fried in HOSBO had higher rancid flavor intensity than the other samples, even though the hexanal levels were significantly lower.

### Conclusions

Results from this study showed that increasing the oleic acid content to very high levels did produce good oxidative stability for HOSBO by OSI, good frying stability for the HOSBO as measured by total polar compounds (Table 2), and good oxidative stability of the stored potato chips fried in HOSBO as measured by hexanal contents (Figure 6). On the other hand, the sensory evaluation of the potato chips fried in HOSBO showed some flavor problems that would not be expected from the chemical and instrumental data. For example, the fishy (Figure 5) and rancid (Figure 4) flavors were easily detectable,

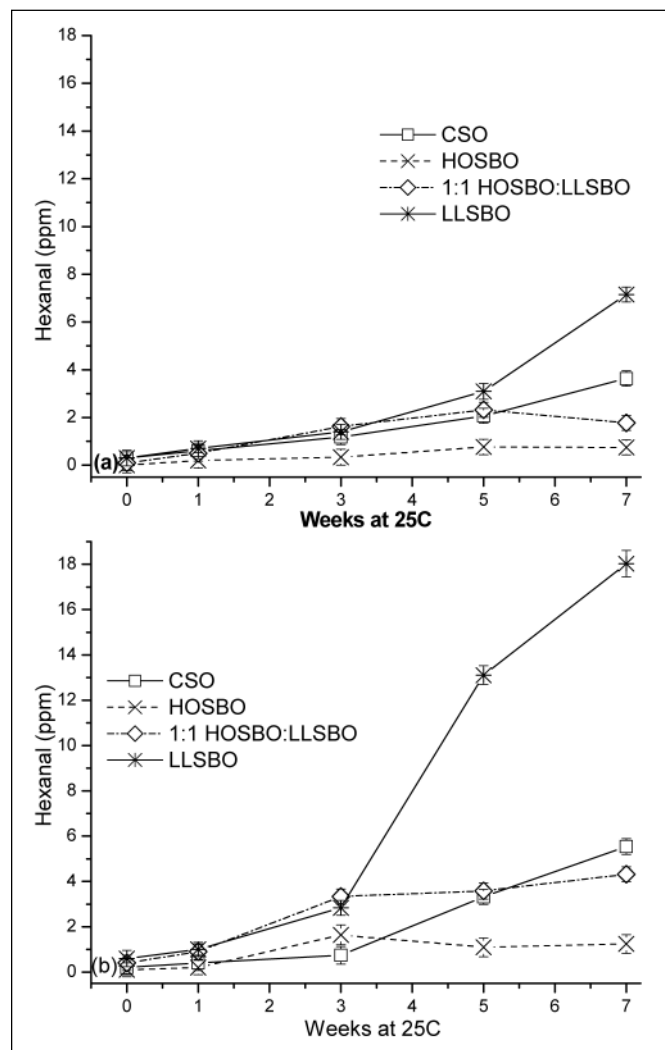
possibly because of the lack of flavors from the fairly stable oleic acid. The potato chips fried in HOSBO had the lowest overall flavor quality scores compared with the other oil types. The unusual fatty acid composition of HOSBO may possibly help explain the lack of correlation of chemical and instrumental data with sensory evaluations. The LLSBO had the lowest OSI value, the lowest frying stability as judged by total polar compounds, and the least oxidative stability as measured by hexanal levels. However, the sensory data showed overall flavor quality scores to be significantly better than the potato chips fried in HOSBO. The linoleic acid content of LLSBO may be too high for good stability; however, it does seem to provide good flavor quality. The blend of 50% HOSBO and 50% LLSBO had low total polar compound levels. The potato chips fried in the blend had lower hexanal formation than the chips fried in either CSO or LLSBO. The oil blend produced chips with a moderate intensity of desirable deep fried flavor without the high intensity of stale flavor found in HOSBO and LLSBO and without the higher fishy flavor of HOSBO. The blend of 50% HOSBO and 50% LLSBO may be a logical alternative to the traditional industry frying oil standard of CSO because the blend showed improved oxidative stability of potato chips compared with CSO and LLSBO and improved flavor quality of potato chips compared with HOSBO. The potato chips fried in the blend also had similar flavor quality scores compared with the chips prepared in CSO in the early stages of frying and better scores in the later stages of frying.

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### References

- [AOCS] American Oil Chemists' Society. 1998. Official methods and recommended practices of the American Oil Chemists' Society. 5th ed. Champaign, Ill.: AOCS.
- Eskin NAM, Vaisey-Genser M, Durance-Todd S, Przybylski R. 1989. Stability of low linolenic acid canola oil to frying temperatures. *J Food Sci* 66:1081-4.
- Evans CD, Moser H, McConnell DG, Cowan JC, Cartter JL, Collins FI. 1965. Flavor evaluation of natural soybean oils of high and low linolenic content. *J Food Sci* 42:736-8.
- Frankel EN. 1985. Mechanisms, products and flavor significance. In: Min D, Smouse T, editors. *Flavor chemistry of fats and oils*. Champaign, IL: American Oil Chemists' Society. p 1-36.
- Fuller GM, Diamond MJ, Applewhite TH. 1967. High-oleic safflower oil: stability and chemical modification. *J Am Oil Chem Soc* 44:264-8.
- Fuller GM, Guadagni DG, Weaver ML, Notter G, Horvat RJ. 1971. Evaluation of oleic safflower oil in frying potato chips. *J Food Sci* 36:43-8.
- Fuller GM, Kohler GO, Applewhite TH. 1966. High oleic acid safflower oil: a new stable edible oil. *J Food Sci* 31:477-80.
- Lahtinen, RM, Wester I, Niemela JRK. 1996. Storage stability of crisps measured by headspace and peroxide value analyses. *Grasas Aceites* 47:59-62.
- Miller LA, White PJ. 1988. High-temperature stabilities of low-linolenate, high-stearate and common soybean oils. *J Am Oil Chem Soc* 65:1324-7.
- Mounts TL, Warner K, List GR, Kleiman R, Hammond EG, Wilcox JR. 1998. Effect of altered fatty acid composition on soybean oil stability. *J Am Oil Chem Soc* 65:624-8.
- Niemela JRK, Wester I, Lahtinen, RM. 1996. Industrial frying trials with high oleic sunflower oil. *Grasas Aceites* 47:1-4.
- Petukhov I, Macolmson LL, Przybylski R, Armstrong L. 1999. Storage stability of potato chips fried in genetically modified canola oils. *J Am Oil Chem Soc* 76:889-96.
- Purdy RH, Campbell BJ. 1967. High oleic acid safflower oil. *Food Technol* 21(3):349-50.
- Snedecor GW. 1956. Statistical methods. 5th ed. Ames, Iowa: Iowa State Univ. Press.
- Warner K. 1995. Sensory evaluation of oils and fat-containing foods. In: Warner K, Eskin NAM, editors. *Methods to assess quality and stability of oils and fat-containing foods*. Champaign, Ill.: American Oil Chemists' Society. p 49-75.
- Warner K, Evans CD, List GR, Boundy BK, Kwolek WF. 1974. Pentane formation and rancidity in vegetable oils and in potato chips. *J Food Sci* 39:761-5.
- Warner K, Knowlton S. 1997. Frying quality and oxidative stability of high oleic corn oils. *J Am Oil Chem Soc* 74:1313-20.
- Warner, K, Mounts TL. 1993. Frying stability of soybean and canola oils with modified fatty acid compositions. *J Am Oil Chem Soc* 70:983-8.
- Warner, K, Orr, P, Glynn, M. 1997. Effect of fatty acid composition of oils on flavor and stability of fried foods. *J Am Oil Chem Soc* 74:347-56.
- Warner K, Orr P, Parrott L, Glynn M. 1994. Effect of frying oil composition on potato chip stability. *J Am Oil Chem Soc* 71:1117-21.



**Figure 6—Hexanal content of potato chips fried in cottonseed oil, high oleic soybean oil (HOSBO); 1:1 blend of HOSBO and low linolenic acid soybean oil (LLSBO); or LLSBO at 5 h (a) or 25 h (b) at 190 °C and stored for 0, 1, 3, 5, or 7 wk at 25 °C**